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Germination of Seeds and Damping-off and Growth of Seedlings of Ornamental Plants as Affected by Soil Treatments

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Heavy losses from damping-off, commonly experienced, have aroused interest in more practical methods for control and prevention. This bulletin reports results from recent investigations in this field.

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GERMINATION OF SEEDS AND DAMPING-OFF AND GROWTH OF SEEDLINGS OF ORNAMENTAL PLANTS AS AFFECTED BY SOIL TREATMENTS

By William L. Doran, Research Professor of Botany

INTRODUCTION AND METHODS

The production of ornamental plants is an important industry in Massachusetts, receipts from their sales comparing favorably with receipts from such other leading crops as apples, tobacco, potatoes, and onions; and there are, of course, many amateur gardeners in the State for whom gardening is a recreation.

As is well known both to professional plantsmen and to those who find in gardening an avocation, a principal problem in the propagation of plants from seed is the damping-off disease by which germination is injured and seedlings weakened or killed. This disease, too generally recognized to need description here, is controllable by known methods of soil disinfection; but it is doubtful whether any of them are sufficiently effective against fungi, during a long enough period, and at the same time sufficiently safe to plants and low in cost, to be altogether satisfactory in more than a limited way. Thus, according to Newhall (69)[1], the cost of soil sterilization by formaldehyde is more than $400 per acre. The search for better, safer, and less expensive soil fungicides continues and this bulletin, which includes also some reference to the work of earlier investigators, is a summary of the results of some of the writer's investigations in this field.

Damping-off of seedlings may be caused by species of at least eight genera of fungi (38), but those most common here and the only ones involved in this work are *Rhizoctonia solani* Kühn and species of Pythium. They were isolated from infected seedlings and several strains of them, in culture, were also obtained from other investigators[2]. Although at least two species of Pythium were used, no distinction is made between them, for a control measure effective against one was equally so against another. The strain of *Rhizoctonia solani* used most often was isolated from thyme, the mats of which are often severely injured by this fungus in rainy summers.

Soil was autoclaved several days before inoculation, and the inoculum, the fungus in culture, was well worked into the soil three or four days before it was used. It many cases naturally contaminated soil was also used, in a supplementary way, for the artificial inoculation of an autoclaved soil may mean an unreasonably drastic test of soil fungicides. Fungi were not reisolated from inoculated soil, but they were isolated from damped-off seedlings in such soil.

Seeds (or, in a few cases, cuttings) of the species of ornamental plants listed in the appendix were used. These species are referred to in the text in more abbreviated ways. Use was also made of a number of vegetables—beet, cress (*Lepidium sativum* L.), cucumber, pepper, etc.

Frequent reference is here made to the effect of soil treatments on growth, and the evidence supports the conclusion of Delafon (27) that a soil disinfectant which is good for use with some species of plants may not be at all good with some

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[1]Reference is made by number to "Literature Cited".

[2]G. P. Clinton, Annie P. Gravatt, C. E. F. Guterman, L. W. R. Jackson, and George L. Peltier.

others. The measure of growth was green weight of seedlings. The most common evidence of stimulation observed was when Rhizoctonia interfered with growth of seedlings in untreated soil, without killing them. Clayton (20) also noticed that plants grew more rapidly in soil which had been freed of Rhizoctonia by formaldehyde, and the writer is of the opinion that much of the so-called stimulatory effect of formaldehyde and other soil disinfectants is thus explainable. This would be less true, however, when only Pythium was involved, for it is more likely to kill quickly than merely to retard the growth of seedlings.

Seedlings were usually weighed at that age and stage of development at which they are ordinarily transplanted for the first time. What the effects might have been had plants been allowed to grow until flowering, was not determined.

"Damping-off" means post-emergence damping-off unless otherwise indicated, in which case the reference is to the killing of seeds or of seedlings before they had emerged from the soil, and this is more commonly discussed in connection with the effect of treatment on germination. Such effects, provided of course that germination is uninjured by the treatment, are less important, however, than are numbers which germinate and live; in other words, final stands. Final stands are a measure of protection against both pre-emergence and post-emergence damping-off, for approximately the same number of seeds of a given species was used with each treatment in any one experiment.

MEDIA FOR SEEDAGE AND THEIR RELATION TO DAMPING-OFF

As has been well demonstrated by Dunlap (31), there is little or no damping-off of seedlings in washed sand. To provide the necessary plant food, he added to the sand, before seeding, about 2.8 gm. potassium nitrate in 142 cc. water per square foot (1 ounce in 3 pints water for 10 square feet). He found that some species grew better in a mixture of sand and peat moss than in sand.

Some use was made of Dunlap's method, comparing soil, washed sand, sand and sphagnum, and sand and peat moss (about half and half by volume in both cases). Five different sands were used. The media were 3 to 4 inches deep in flats with narrow seams in the bottom. Sands always received potassium nitrate, before seeding, at the rate of 2.8 or 3.0 gm. in 140 or 150 cc. water per square foot.

It was soon evident that sand–sphagnum and sand–peat moss need the nutrient about as much as does sand, for the addition of potassium nitrate increased the weights of plants as follows:

	Percentage Increase due to Fertilizer	
	In Sand–peat	In Sand–sphagnum
Calendula	14	11
Cress	55	50
Beet	59	38

In all later experiments, therefore, potassium nitrate was applied to these media as well as to sand. Soil, of course, received no nutrient.

Results are summarized in Tables 1 and 2, both of which include the means of several experiments. There was little or no damping-off in sand. There was a little more damping-off in sand–sphagnum and in sand–peat moss than in sand, but much less than in soil.

Damping-off was as completely prevented and final stands were as much improved by the use of washed sand as a medium for seedage as by the disinfection of soil with formaldehyde.

TABLE 1.—DAMPING-OFF AND FINAL STANDS IN DIFFERENT MEDIA

Media	Percentages which Damped-off		Relative Numbers of Plants which Lived				
	Beet	Cress	*Viola cornuta*	Marigold	Beet	Cress	Lettuce
Soil...........	45	32	100	100	100	100	100
Sand...........	0	1	168	172	266	287	528
Sand-sphagnum.	2	3	205	197	219	337	523
Sand-peat moss..	3	6	159	197	198	249	478

Although washing with hot water frees sand from fungi, it does not prevent their growth if they are reintroduced. In one experiment in which where was no damping-off in washed sand, damping-off was severe when this same sand was inoculated with Pythium. In this connection it is of interest to note that, in the experiments of Abdel-Salam (3), Pythium caused severe damping-off in inoculated sand; but Rhizoctonia caused only 2 percent damping-off in inoculated sand, although it caused 74 percent damping-off in loam. It would seem that washed sands which later become contaminated with Pythium may be more dangerous to seedlings than washed sands contaminated with Rhizoctonia. This defect of washed sand is, of course, not unique with it, for disinfected soil may also become recontaminated with fungi.

As has been shown by Dunlap, the same sand may be used repeatedly if it is well washed with hot water before each seeding. When this practice was followed with sand–sphagnum or sand–peat moss in these experiments, however, there was a little more damping-off than in sand so treated, indicating that washing these media may not free them so completely of fungi as does the washing of sand.

As may be seen by reference to Table 2, none of the species grew so well in sand as in soil. This was true of beet and cress in five different sands, and also of Zinnia, English daisy, and ten-weeks stock in the only sand in which they were seeded. Growth was better in sand than in soil in a few instances, but only when Rhizoctonia, without actually killing the seedlings, seriously interfered with their growth in soil.

TABLE 2.—AVERAGE GREEN WEIGHT PER PLANT IN DIFFERENT MEDIA

(Weights expressed as relative numbers.)

Media	Calendula	Canterbury bells	Marigold	Salpiglossis	*Viola cornuta*	Beet	Cress	Lettuce	Spinach
Soil...........	100	100	100	100	100	100	100	100	100
Sand B.......	—	—	—	—	56	63	76	—	—
Sand H.......	—	—	—	—	100	68	74	—	—
Sand P........	—	—	—	—	78	43	48	—	—
Sand N.......	—	—	—	—	70	67	49	—	—
Sand S........	64	34	68	50	82	48	80	78	44
Sand S and sphagnum...	121	100	—	—	125	91	129	123	69
Sand S and peat moss...	88	100	—	—	106	105	112	112	53

Sands had pH values of 5.8 to 6.1 and water-holding capacities of 24 to 27 percent. They differed more in degree of fineness, and the poorest growth was most often in the finest sand. This is in agreement with observations of Dunlap; and Biekart and Connors (10) preferred a medium-coarse to a finer sand for the culture of carnations in sand.

Growth of seedlings of all species was better in sand–sphagnum and sand–peat moss than in sand alone (with usually a little more benefit from the sphagnum), probably because moisture and nutrients were retained better in these media than in sand. Growth was usually as good in sand–sphagnum and sand–peat moss as in soil, and often better. Peat moss increased the water-holding capacity of the sand and lowered its pH value more than did the sphagnum.

It is evident from the above that sand culture of seedlings controls damping-off, but it is perhaps no more convenient to wash sand and apply nutrients once (or more than once, as Dunlap suggests) than it is to disinfect soil chemically. The principal defect of sands—at least of some sands—is that growth of seedlings may be too slow unless nutrient is applied more than once. Seedlings of tuberous-rooted begonias, Ramondia, *Primula denticulata* and other species grew too slowly in sand to be of a size easy to transplant to better soil when they should have been. There seems to be ample justification for the English horticultural writer (1) who considers sand an ideal medium for germination except for the fact that it requires such vigilant watering (which may mean washing out of nutrient) that it may be necessary to add peat moss to the sand to retain moisture.

Sphagnum was found no less useful. The sand used in such a mixture should be washed with hot water, and the mixture of sand with peat moss or sphagnum needs nutrient about as much as does sand alone.

The medium used in the experiments with soil fungicides was a sandy soil made by mixing a sifted compost of sods and manure with sand, half and half by volume. Soils used for seedage of most species ought to be sandy rather than heavier because of the greater risk of the latter's caking and remaining excessively wet too long if overwatered. It is not to be supposed, however, that the proportion of sand in the soil will have much effect on the severity of damping-off; and in these experiments, as in those of Gratz (39) and Abdel-Salam (3), damping-off caused by Rhizoctonia was severe in a mixture (half and half) of loam and sand. This was true also when such a soil was inoculated with Pythium.

There are soils in the trade which have already been sterilized by the firms supplying them, and, unless they later become contaminated, there is little or no damping-off in them. To lessen the cost of using such soil, it was mixed with washed sand up to half and half. No increase in damping-off resulted, and seedlings grew well without the addition of nutrient up to the stage at which they are commonly transplanted.

SOIL REACTION AND DAMPING-OFF

Certain plant diseases are known to be at least partly controllable by adjusting soil reaction. It is, therefore, of interest to learn to what extent such methods might be expected to be effective in the case of damping-off.

Although investigators are not in complete agreement, it appears from the work of Anderson (6), Jackson (52), and Jones (55) that species of Pythium may cause severe damping-off in soils having pH values of 4.5 or 5.0 to 6.5 or 7.0 and that they may cause some damping-off even in soils with pH values of less than 4.0. That being the case, a soil which is acid enough to inhibit Pythium as a pathogen will probably be too acid for many species of plants.

Going to the other extreme, high pH values, it should be noted that lime as applied to soil by Johnson (54) did not protect seedlings against infection by Pythium. Similar results were obtained here with seedlings of Delphinium and several species of Dianthus when hydrated lime, up to 2 tons per acre, was applied to soil (inoculated with Pythium) which had an initial pH value of 5.0.

Buchholtz (15) was able to reduce the severity of damping-off by a heavy application of lime, it is true, but his soil had an initial pH value of 6.2, and it is reasonable to assume that this may have modified the effect of liming. In a soil with an initial pH of 4.5, an application of lime which changes the pH value to 6.0 might be expected to make damping-off caused by Pythium not less but more severe.

Turning now to Rhizoctonia, it has been established by several investigators (93, 39, 52, 63) that this fungus can grow, at least in culture in artificial media, at pH values ranging from a minimum of pH 2.0 to 3.0 to a maximum of pH 9.0 to 10.0, with the optimum at about pH 6.0 or 7.0. This is a wider range and a higher optimum than that reported by others for Pythium. It does not appear that damping-off caused by Rhizoctonia would be at all readily or practically controllable by the adjustment of soil reaction. Peltier (73) observed that it grew equally well in acid and alkaline soils; Gloyer and Glasgow (38) found it growing well in soil with a pH value of about 7.4; and in experiments of Jackson (52), there was some damping-off until pH values were lowered to 2.5, although the disease was more severe at or near neutrality.

These relations are further mentioned in connection with the use of certain chemicals, especially sulfur, aluminum sulfate, and calcium salts.

SOIL MOISTURE AND DAMPING-OFF

Soil used in seedage is often watered unnecessarily heavily, as a result of which, especially if the soil is inclined to heaviness, it so shrinks, bakes, and cakes as to interfere with germination about as much as fungi do.

Chemical treatments mentioned below were applied to soils which were moderately dry. Soils were watered immediately after seeding. Water was usually applied through papers laid on the soil, so that seeds would be neither washed out nor buried. These papers were left on until seedlings began to emerge. This helps to prevent a too prompt recontamination of the soil, as by dirt blowing upon it, but is unnecessary as far as holding fungicides in the soil is concerned.

Damping-off fungi are sometimes present in water, in which case they may be destroyed by boiling, and some investigators (71, 5) have done that before watering sterilized soil. This was unnecessary with the water used in these experiments, however; for, in sterilized soil, there was as little damping-off of seedlings watered with tap water as of those to which only boiled water was applied.

It has been suggested that damping-off may be at least partly controlled by less heavy or less frequent waterings and by more ventilation, but the indications are that this would be neither easy nor safe. Abdel-Salam (3) concluded from his experiments that a high degree of dryness of the air does not stop the spread of the disease once it has appeared. Alexander and his associates (5) came to the similar conclusion that damping-off caused by Pythium and Rhizoctonia cannot really be controlled in practice by regulating soil moisture; and Gratz (39) found that Rhizoctonia infected plants at any soil-moisture content favorable to their growth. Abdel-Salam had similar results, a strain of Rhizoctonia causing as severe damping-off in relatively dry as in much moister soils. It would appear, therefore, that a soil too dry for damping-off is probably too dry also for germina-

tion and good growth. This may be especially true with small seeds, usually sown on the soil surface, for they cannot become dry after germination has begun without some likelihood of injury.

Very small seeds are best watered from below, by the partial immersion of pots in water, for there is then less danger of seeds and seedlings being washed out or buried. Bewley (9) and Gratz concluded that this is also less favorable to damping-off caused by Rhizoctonia than is watering from above. Neither of them asserted that the disease is thus entirely preventable, however; and in the writer's experiments with Pythium, there was about as much damping-off of Nicotiana and Canterbury bells when they were watered from below as when they were watered from above through papers. Soil watered from below may receive too much water at one time and, therefore, remain wet too long unless well and promptly drained. This is more likely to happen with soil of high water-holding capacity or one which contains much peat moss, but there is not much risk in the case of a sandy soil.

TEMPERATURE AND DAMPING-OFF

Earlier investigators (39, 3, 46, 89, 75) have found that Rhizoctonia may infect seedlings and cause damping-off at temperatures from as low as 45° to 48° F. (7° to 9° C.) to as high as 86° to 95° F. (30° to 35° C.), with the optimum temperature for infection variously identified as between 59° and 86° F. (15° to 30° C.).

It has been suggested (54, 9) that temperatures be lowered to help protect seedlings against Rhizoctonia but, on the basis of the figures presented above, the temperatures might have to be lowered to below 60° F. before damping-off could be expected to be checked, and Bewley (9) indicates that there may be no decrease in the disease caused by this fungus until temperatures have been brought down to below 54° F., which is too low for many species of plants.

Cardinal temperatures for damping-off caused by Pythium have been reported by other investigators as follows:

Minimum: Below 59° F. (5), below 55° F. (46), or 46° F. (3)

Optimum: 86° F. (3), 86° to 68° F. (46), or 75° to 64° F. (5)

Maximum: 95° F. (3), above 86° F. (80), or 86° F. (46)

It appears, therefore, that both Pythium and Rhizoctonia may cause damping-off at temperatures from maxima of 95° to 86° F. (35° to 30° C.) down to minima of 48° to 46° F. (9° to 8° C.), with the optimum for Pythium between 64° and 86° F. (18° to 30° C.) and the optimum for Rhizoctonia between 59° and 86° F. (15° to 30° C.).

It has been suggested (54) that, in an effort to control Pythium, temperatures be lowered to below 70°F., and the results of others, summarized above, do indicate that less infection by Pythium may be expected at temperatures below about 66° F. There may, however, be some infection of seedlings by Pythium at temperatures as low as 46° F., and the writer has found no published record of complete control of damping-off caused by Pythium by temperature regulation without some adverse effect on germination of seeds or growth of seedlings of some species.

SOIL FUNGICIDES AND DAMPING-OFF

It appears from the foregoing discussion that damping-off is not altogether controllable by the adjustment of the environment. It is, of course, controllable by ridding the soil of fungi, as by the use of various chemicals, although there is need of fungicides which will prevent the recontamination of soils for a longer time than do the commonly used volatile chemicals. Steam is subject to the same criticism, and Anderson (6) concluded that Pythium rapidly reinfests soil thus sterilized, the fungus growing up, in tobacco beds, from unsterilized soil below. He suggested the use of formaldehyde instead of steam, but there is no evidence that its fungicidal effect is much less fleeting and it has been noted by Thomas (85) and by others that formaldehyde treatment of soil does not for long prevent the reintroduction of pathogenic fungi.

This is really no great drawback when only damping-off or early damping-off is to be combated but may be serious with seeds which are slow to germinate or seedlings of species which remain susceptible to infection by soil fungi for a long time. It is true that the susceptibility of most species to damping-off, especially to that caused by Pythium, usually decreases fairly rapidly as plants grow older; but damping-off fungi may injure plants in other ways, and Gratz (39) found that Rhizoctonia may infect seedlings of cabbage until they are more than four months old.

Once the pathogenic fungi have been introduced into soil which was (steam) sterilized some time before, they may cause even more damping-off than in soil not sterilized at all. This was the conclusion of Hartley (43) and of Abdel-Salam (3) with reference to Pythium and Rhizoctonia respectively. Horsfall (48), too, observed that damping-off may be worse in reinfested soil than it was before steaming, and Abdel-Salam made a similar observation in connection with the use of formaldehyde.

It is evident, then, that such treatments are more effective in getting fungi out of soil than in keeping them out, and just how soon sterilized soil may be reinfested is a point of some interest. Pythium grew in soil inoculated by Nolla (71) one week after treatment with formaldehyde, and he applied it twice as heavily as is usually recommended. This indicates that soils so disinfected may become recontaminated with fungi (although, of course, they often do not) by the time seeds are planted, especially if, on the grounds of safety, there is some delay between disinfection of soil and seeding.

We may now, on the basis of the above discussion, consider in some detail the use of a number of chemicals, for more needs to be learned about better methods of using old soil disinfectants and about other chemicals which may have more nearly ideal qualities as soil disinfectants.

Formaldehyde

Formaldehyde has been applied to soil in many different ways. Table 3 includes mention of several representative methods, the number of cubic centimeters of commercial formaldehyde[3] and of water applied per square foot, and results in control of damping-off.

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[3]37 percent by weight, 40 percent by volume.

TABLE 3.—RESULTS OF OTHER INVESTIGATORS WITH FORMALDEHYDE AS A SOIL DISINFECTANT

Literature Citation	Dilution and Application per Square Foot	Number of cc. per Square Foot: Commercial Formaldehyde	Number of cc. per Square Foot: Water	Resulting Control of Damping-off
Johnson (54)	1:50, 2 quarts	37.8	1855	Prevented infection by Pythium and Rhizoctonia
Clayton (20)	1:50, applied to soil saturation			Prevented infection by Rhizoctonia
Johnson (54)	1:75, 2 quarts	25.0	1868	Did not prevent infection by Pythium and Rhizoctonia for more than 15 days
Brien and Chamberlain (13)	1.0 percent solution, 1.33 quarts	13.0	1246	Prevented infection by Pythium and Rhizoctonia
Weindling and Fawcett (95)	6.0 percent *dust*, 3 ounces	13.0	0	Prevented infection by Rhizoctonia
Brien and Chamberlain (13)	0.83 percent solution, 1.33 quarts	10.5	1249	Did not prevent infection by Rhizoctonia, but sometimes controlled Pythium
Guterman and Massey (40)	Applied 12 to 24 hours before seeding. Soil well watered after seeding	7.1	39	Controlled damping-off as well as formaldehyde dust
Wilson and Tilford (100)	6.0 percent *dust*, 1.5 ounces—the common recommendation for dust	6.37	0	Killed Pythium: also the mycelium but not the sclerotia of Rhizoctonia
Weindling and Fawcett (95)	6.0 percent *dust*, 1.5 ounces	6.37	0	Failed to prevent infection of citrus seedlings by Rhizoctonia
Guterman and Massey (40)	Applied immediately before seeding. Soil well watered after seeding	5.0–3.3	27–18	Controlled damping-off as well as formaldehyde dust

Acetic acid is sometimes less effective against Rhizoctonia than against Pythium, and there are indications that formaldehyde, too, may be less effective in preventing damping-off caused by Rhizoctonia than that which is caused by Pythium. Thus Wilson and Tilford (100) observed that the formaldehyde dust treatment which kills Pythium (and certain other fungi) in soil also kills the mycelium, but not the sclerotia, of Rhizoctonia; and Weindling and Fawcett (95) concluded that it may be necessary to use 3 ounces of formaldehyde dust per square foot (instead of 1.5 ounces as commonly recommended) to prevent infection of citrus seedlings by Rhizoctonia. Brien and Chamberlain (13) also found that an application of formaldehyde which was at least partly effective against Pythium was completely ineffective against Rhizoctonia. Hartley (43), too, noted that formaldehyde does not always rid soil of Rhizoctonia, and Peltier (73) was not altogether successful in protecting carnations against this fungus with formaldehyde.

An application of this or other chemical may, of course, be too light to kill either fungus; but, as may be seen from Table 3, damping-off has been satisfactorily prevented by as little as 7, 5, or even 3 cc. formaldehyde per square foot. These are very small applications, compared with the 37 cc. per square foot which results when 2 quarts of the 1:50 dilution of formaldehyde, long a standard recommendation, is applied. That method is going out of favor, principally because of the 10 to 14 days' delay necessary between soil treatment and seeding. Yet an application of two quarts per square foot of a slightly weaker solution, 1:75, equal to about 25 cc. formaldehyde per square foot, was found by Johnson (54) to be ineffective against both Pythium and Rhizoctonia after 15 days. It may be that some of the smaller applications (such as the 6.37 cc. of formaldehyde in 1.5 ounces of a 6 percent dust) would not be effective for any longer; but they are generally used with satisfactory results (100, 40).

These new methods differ from the old, and this may be important, in that less water as well as less formaldehyde is applied per square foot—as much as 1855 cc. by the old method, and as little as 30 cc. or none at all by the new. The explanation is probably to be found in the conclusion of Yu (102) that the fungicidal effects of formaldehyde (and of acetic acid) are greater if soil to which they are applied is not very wet. It may be necessary to add more water to soil at time of seeding, but the indications are that less of the fungicide is needed if not too much water is applied with the treatment, especially if the chemical is mixed with the soil. Then too, formaldehyde has been found to escape more rapidly from a drier than from a wetter soil (100), which is one explanation of why the time interval before seeding may safely be shorter.

But the less dilute the chemical when applied to soil, the greater may be the need of later watering, at time of seeding, to prevent injury. This is the common recommendation when formaldehyde dust is used, and Guterman and Massey (40) found it necessary to water thoroughly, after seeding, soil which had been treated with formaldehyde (about 7 cc. per square foot in about 40 cc. of water) 24 hours previously. The writer has found their method effective against damping-off and safe with the seeds used, but there was injury to cuttings of an herbaceous plant, *Nepeta Mussini*, inserted 24 hours after this treatment of a sandy soil.

Haensler (41) was able to control damping-off by formaldehyde 1:300, applied at the rate of 0.75 quart per square foot immediately after seeding. This is a very light application of formaldehyde indeed, only about 2.3 cc. per square foot; but, as used by the writer, it markedly improved germination and prevented most early damping-off. It was not injurious to tomato, eggplant, pepper, or lettuce. It did injure cress, crucifers being more subject to injury by formaldehyde, as Haensler observed, than are some other plants. Such use of fungicides, after rather than before seeding, is further discussed below.

Acetic Acid, Acetic Acid Dusts, and Vinegar

The soil in these and the following experiments was 3 to 4 inches deep in flats or earthen pans. Chemicals were applied on the basis of the number of grams or cubic centimeters per square foot of soil surface.[4] Except as otherwise noted, chemicals were worked into the soil before seeding.

Acetic acid 1.0 to 1.2 percent (2 quarts per square foot, 1 or 2 weeks before seeding) was found (28, 29) to be a safe and effective soil disinfectant. As has been pointed out by Newhall, Chupp, and Guterman (70), it is less unpleasant

[4]One gm. per square foot is 96 pounds per acre, and 20.8 gm. per square foot is 1 ton per acre.

to breathe then formaldehyde and, in well-ventilated greenhouses, it can be used with less injury near plants. In the work of Yu (102), acetic acid 1.5 percent was also less injurious to germination of cucumber than was formaldehyde 1:50, with both applied 9 days or more before seeding. Since its merits were first pointed out, other investigators have used it with good results. (See Table 4.)

It is of interest to note, however, that Christoff (18), using a 1.0 percent solution, controlled damping-off of conifers more completely in an acid than in a highly alkaline soil; but with the latter, the writer has had no experience.

Table 4.—Results of Other Investigators with Acetic Acid as a Soil Disinfectant

Literature Citation	Fungi Involved	Dilution, Application per Square Foot, and Days before Seeding	Results
Flachs (36)	Sclerotinia	1.5 percent, 1 quart	Damping-off of lettuce well controlled
Gill (37)	Pythium and Rhizoctonia	1.0 percent, 1 quart, 7 to 10 days	Control of geranium cutting rots compared favorably with that by formaldehyde 1:50
Brien and Chamberlain (13)	Pythium and Rhizoctonia	1.0 percent, 1.3 quarts, 14 days	Damping-off of tomato seedlings well controlled
Christoff (18)	Pythium and Rhizoctonia	1.0 to 1.2 percent, 1 quart, 7 to 10 days	Damping-off of seedling conifers well controlled
Yu (102)	Pythium	1.5 or 2.0 percent, 2 quarts, 9 to 13 days	Damping-off of cucumber well controlled
Sherbakoff (80)	Septoria	1.0 percent	Good control of tomato leaf spot, when supplemented by spray of Bordeaux mixture
Anderson (6)	Pythium	1.0 percent, 2 quarts, 7 days or more	Damping-off of tobacco well controlled

Acetic acid 1.0 or 1.5 percent (approximately) may be made by diluting glacial acetic acid 1.0 or 1.5 gallons to total 100 gallons. Two quarts of these dilutions per square foot cannot be applied less than one week before seeding without injury to some species; for example, foxglove, sweet pea, and beet. Cucumber is more tolerant. A 1.5 percent solution applied 10 days before seeding was harmless to these species and to *Veronica repens*, *Cheiranthus Allionii*, and *Lilium philippinense*. All damping-off was prevented, germination was improved, and, because of infection by Rhizoctonia in checks, growth was improved.

The effect of acetic acid on the pH value of treated soil does not usually last more than two or three weeks.

A principal objection to acetic acid, as to formaldehyde, thus used is the delay of a week or two before seeding and this, in the case of formaldehyde, has been overcome by the use of the dust. Guterman and Massey (40) were equally successful in using a small quantity of formaldehyde (about 7 cc. per square foot in 5 times that volume of water) 12 to 24 hours before seeding, the soil being then well watered.

Acetic acid 80 percent, 8 cc. per square foot, thus diluted and mixed with soil did not injure Torenia, Verbena, Calendula, cabbage, and pepper and it did improve their germination without, however, preventing all damping-off.

Acetic acid 80 percent, 8 cc. per square foot, and also formaldehyde 7cc., each diluted with 5 times that volume of water, were also applied to (but, of course, not mixed with) soil immediately after seeding. Thus used they were injurious to Felicia, Linanthus, *Mathiola bicornis*, as well as the species mentioned above, which were uninjured when these quantities of acetic acid or of formaldehyde were mixed with soil before seeding. Pepper, seeds of which germinate slowly, was least injured by these treatments applied after seeding.

Acetic acid dusts, on the use of which the writer has briefly reported (30), were made by mixing the acid with powdered wood charcoal. Some of the best, containing 23 or 24 percent acetic acid, consisted of 1 pint of 80 percent acetic acid with 2.5 or 2.75 pounds of charcoal, or 1 pint of glacial acetic acid with 3.5 pounds of charcoal. These were stored in practically airtight containers and worked into the soil shortly before seeding, at the rate of 1.5 ounces per square foot. Soils were well watered immediately following seeding.

In soils inoculated with Pythium and Rhizoctonia, germination was improved and the severity of damping-off was lessened by a 15 percent dust, but the control of damping-off was increasingly good when dusts contained 18 to 24 percent acetic acid, with best control by the 23 and 24 percent dusts.

The relative numbers of plants which lived are recorded in Table 5, which includes the means for several experiments. A 23 percent acetic acid dust also improved germination of Browallia, Cerastium, English daisy, columbine and lupine.

TABLE 5.—EFFECT OF ACETIC ACID DUSTS ON FINAL STANDS

Percentage of Acetic Acid in Each Dust	Relative Number of Plants which Lived						
	China Aster	Dahlia	Delphinium	Sweet Pea	Zinnia	Beet	Cress
Check.......	100	100	100	100	100	100	100
19...........	—	383	—	—	—	210	722
22...........	—	380	—	193	196	—	1283
23...........	417	—	—	275	—	554	4056
24...........	573	—	221	282	218	535	4020

The effect of a 23 percent dust in improving stands is also shown in Figure 1. This dust, applied to soil immediately or within 24 hours before seeding, was harmless to the species named in Table 5 and above, and also to rocket, Laburnum, arbor-vitae, onion, *Rhododendron calendulaceum*, *R. catawbiense*, *R. carolinianum*, and *R. Schlippenbachii*. Perhaps it would not be harmless to all species, for Alexander, Young, and Kiger (5) injured tomato seeds with a 20 percent acetic acid dust, although their carrier was not charcoal but diatomaceous earth and kaolin.

These acetic acid dusts, as made and used by the writer, were, however, unsafe with cuttings, for even a 17 percent dust, applied to a mixture of sand and peat moss 24 hours before their insertion, injured Ilex, Berberis, *Lonicera pileata*, Euonymus, Calluna, Chamaecyparis, and Erica.

Vinegar as usually sold contains 4 to 5 percent of acetic acid and it has occasionally been recommended, as by Stafford (82), for the control of damping-off. It is doubtful, however, whether there is much experimental evidence on which to base such recommendations and they usually call for much less vinegar than the writer (30) has found necessary.

Four brands of cider vinegar were used in this work, and the results did not differ significantly one from the other. Undiluted vinegar was worked into the soil immediately before seeding, except as otherwise indicated. Some of these soils had been inoculated with Pythium or Rhizoctonia and others were naturally infested. The soils were well watered immediately after seeding. Results are recorded in Table 6 in terms of percentages which damped-off and relative numbers of plants which lived.

TABLE 6.—EFFECT OF VINEGAR ON DAMPING-OFF AND ON FINAL STANDS

Vinegar cc. per Square Foot	Arbor-vitae	China Aster	*Centaurea Cyanus*	*Cheiranthus Allionii*	Dimorphotheca	*Dianthus arenarius*	Delphinium	Lupine	Mesembryanthemum	Ranunculus	Verbena	Zinnia	Cress	Beet	Lettuce	Spinach
Percentages which Damped-off																
Check...	21		22	49									53	36	25	27
140...	16		—	—									20	—	—	—
175...	5		—	—									16	14	—	—
195...	—		—	8									13	9	7	—
215...	—		3	2									13	4	5	—
235...	—		—	—									8	2	0	6
250...	—		0	0									1	1	0	2
Relative Numbers of Plants Which Lived																
Check..		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
140...		—	—	—	—	—	—	—	—	117	—	—	312	—	—	—
175...		—	—	—	121	163	—	—	—	233	—	—	393	233	—	—
195...		—	167	—	—	—	—	—	133	—	—	—	280	307	—	—
215...		—	204	162	—	265	129	137	142	—	131	—	538	300	316	—
235...		600	229	—	—	—	129	—	—	—	—	196	637	318	343	—
250...		623	225	170	—	258	143	146	167	—	145	189	834	509	343	197

Damping-off caused by Pythium and Rhizoctonia was usually well controlled by 215 cc. vinegar per square foot, with better control by 235 cc. (about one-half pint). Germination of most species, especially those like cress and beet which are very susceptible to damping-off, was usually much improved also. Beneficial effects on stands are illustrated in Figure 1. Vinegar in too small quantities to prevent damping-off, down to 140 cc. per square foot, often improved germination.

As may be seen from the following tabulation, the quantity of vinegar which can be safely used immediately before seeding is not the same for all species.

As compared with check plants infected by Rhizoctonia, growth was often improved by 200 to 240 cc. vinegar.

At present it does not seem wise to suggest the use of more than 237 cc. (one-half pint) of vinegar per square foot, to be worked into the soil immediately before seeding; and lighter applications are sometimes sufficient in soils not too heavily infested with fungi. Homemade vinegar may, according to Wyant (101), have a higher content of acetic acid than the vinegar which is commonly sold, and must, therefore, be used with extra caution unless it has first been diluted to about 4 percent acidity.

Vinegar per Square Foot	Species Injured	Species not Injured
260 cc.	Androsace Beet	China aster Delphinium Celery
255 cc.	Candytuft	
250 cc.	Cress	*Alyssum saxatile* Arenaria Silene Zinnia Cabbage
245 cc.		Arabis Beet Cucumber Spinach

Vinegar per Square Foot	Species not Injured
235 cc.	Androsace Rocket candytuft Calendula Sedum Morning-glory Lettuce Pepper Tobacco Tomato
230 cc.	*Centaurea Cyanus* Lupine Cress
200 cc.	*Mathiola bicornis* Pyrethrum Ranunculus Arbor-vitae

We come now to the use of vinegar applied to the surface of soil *after* seeding. It cannot then be worked into the soil and is, therefore, more concentrated near the surface of the soil and near the seeds. Vinegar, with or without dilution, was thus applied in several experiments and its effects on germination are summarized in Table 7.

Quantities of vinegar which were entirely safe if worked into the soil before seeding were injurious to seeds of some of the same species if applied to the surface of the soil immediately after seeding. The important point seems to be not so much *when* as *how* vinegar is applied, for there was often no more than 10 minutes' difference between applications made after seeding and those made before.

Vinegar applied after seeding was least injurious in the case of seeds which germinate relatively slowly, such as Opuntia or even pepper; and it was most injurious in the case of seeds which germinate relatively promptly, before enough acetic acid has escaped from the soil, such as cabbage and Calendula. Seeds and seedlings of Opuntia, which are prone to damp-off, were well and safely protected by 237 cc. of vinegar, undiluted, applied to soil after seeding. Such an application may, however, be decidedly unsafe with some other species which germinate more rapidly.

Germination was injured more than was growth. Growth of the species named in Table 7, with the exception of cabbage, was unaffected or improved by 237 cc. of vinegar diluted with an equal volume of water. Growth of cabbage was injured by as little as 189 cc. thus diluted.

Not only vinegar, but also acetic acid (80 percent) 8 cc., and formic acid 3.5 cc. per square foot were found to be considerably more injurious when applied to soil after seeding than before, and, as has already been said, as little as 2.3 cc. formaldehyde applied after seeding is injurious to crucifers.

It is not at all certain that such light applications would be for long effective in preventing fungi from growing up from the soil below, but the method has the advantage of convenience and is now being investigated further.

TABLE 7.—EFFECT ON GERMINATION WHEN VINEGAR WAS APPLIED TO SOIL AFTER SEEDING

Application of Vinegar per Square Foot	Germination Injured	Germination Unaffected	Germination Improved
237 cc. undiluted	Agapanthus *Antirrhinum maurandioides*	Calla Lachenalia *Mentha Requienii*	*Opuntia* sp. *O. humifusa* *O. vulgaris*
237 cc. diluted with an equal volume of water	Calendula Cabbage		Pepper Beet Tomato (after a little delay)
220 cc. diluted with water to 3 pints	Felicia Linanthus Cabbage Celery	Pepper	
200 cc. undiluted	Calendula Cabbage	Pepper	
200 cc. diluted with water to 3 pints	Calendula Torenia Verbena Cabbage	Pepper	
189 cc. undiluted	Cabbage		Calendula Beet Pepper
189 cc. diluted with an equal volume of water	Cabbage		Calendula Beet Pepper

In a few cases, soils were watered with diluted vinegar after the emergence of seedlings, and a very little vinegar—too little to prevent damping-off—was then injurious. Twenty cc. per square foot, diluted with whatever water the soil needed and applied whenever water was needed, was harmful to the growth of Ageratum, Thunbergia, cress, and lettuce; and 50 cc., thus applied, was also injurious to beet, pepper, and tomato.

Pyroligneous Acid

This is not a chemical compound, but a mixture of acetic acid and a number of other constituents in water (45). In earlier work (29), the undistilled pyroligneous acid (diluted 4:100, 2 quarts per square foot) prevented most damping-off and was safe to use one day before seeding. This undistilled acid, except as indicated below, had been made by converting hardwoods (birch, beech, and maple) into charcoal and distilling the smoke. It differs from the distilled acid in containing some, or more, wood tar.

The acids were variously diluted, 4:100 meaning 4 parts of the acid with 96 parts of water, and they were, except as indicated below, applied to soil within a few hours before the seeds were sown.

Undistilled pyroligneous acid was more effective in controlling damping-off than was the distilled. Results with each, the means in five experiments, with 2 quarts applied per square foot, are recorded in Table 8. Distilled pyroligneous acid, 6:100, reduced the severity of damping-off, but did not satisfactorily control the disease.

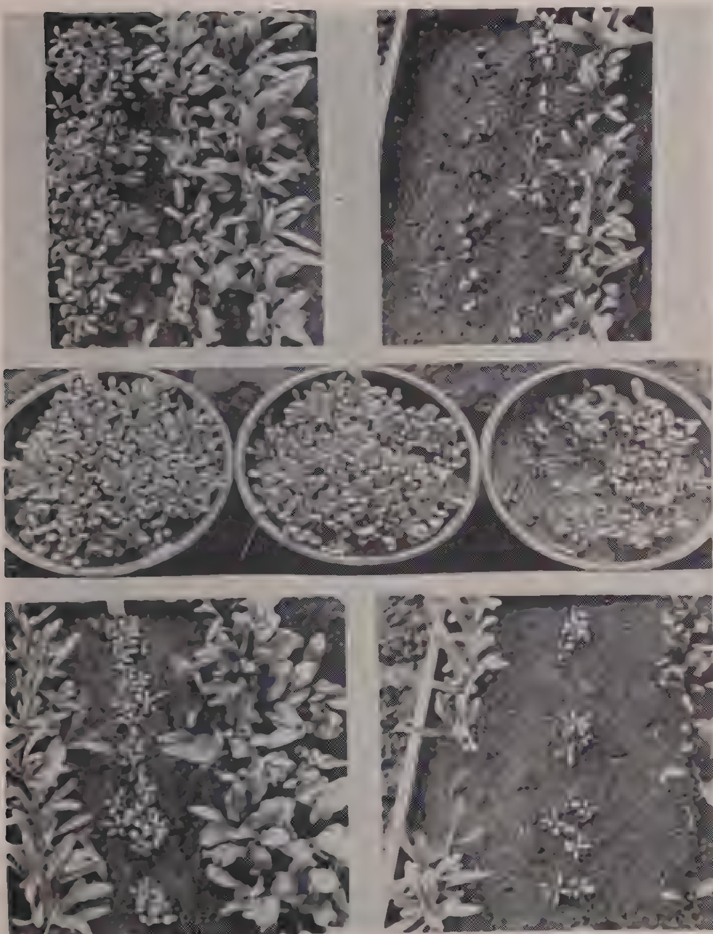

Figure 1. Effect of Acetic Acid Dust and Vinegar on Final Stands.

UPPER: Left--Acetic Acid Dust, 23 percent. Right--Check.
Plants (left to right)--cress, beet, cornflower.

CENTER: Left--Vinegar 237cc. Center--Vinegar 218 cc. Right--Check.
Plants--lettuce.

LOWER: Left--Vinegar 220 cc. Right--Check.
Plants (left to right)--Dimorphotheca, Dianthus arenarius, beet.

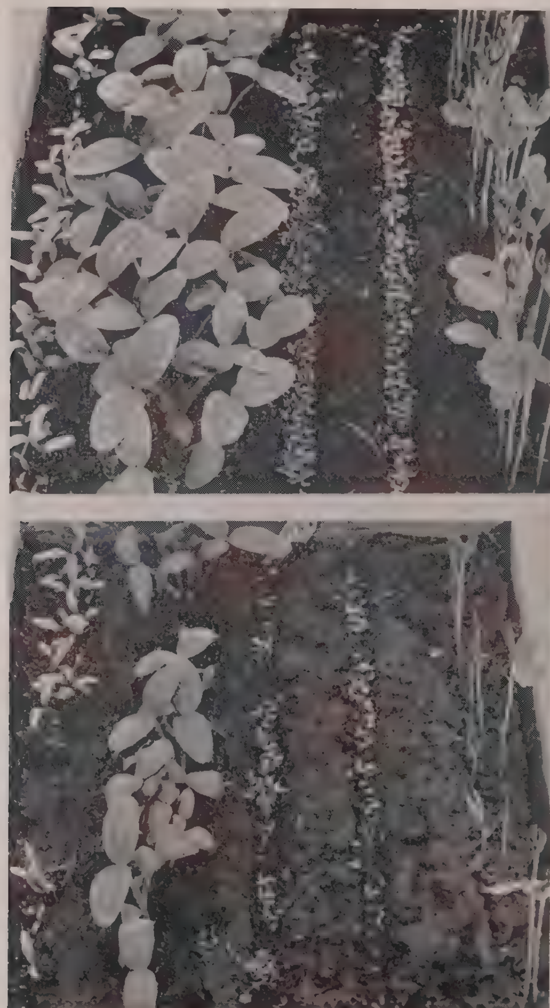

Figure 2. Effect of Pyroligneous Acid on Final Stands.

UPPER: Pyroligneous Acid 5:100.
LOWER: Check.

Plants (left to right)--beet, cucumber, foxglove, Canterbury bell, sweet pea.

TABLE 8.—EFFECT OF PYROLIGNEOUS ACID ON DAMPING-OFF AND ON FINAL STANDS

Soil Treatment	Percentages which Damped-off		Relative Numbers of Plants which Lived	
	Beet	Cucumber	Beet	Cucumber
Check	19	53	100	100
Distilled acid				
4:100	19	40	132	100
5:100	6	31	127	127
6:100	8	15	123	136
Check	19	53	100	100
Undistilled acid				
3:100	4	9	210	293
4:100	0	7	217	453
5:100	0	4	198	565

Damping-off was usually well controlled and germination much improved by undistilled pyroligneous acid 5:100. Its effects on germination and on damping-off are shown in Figure 2. The severity of damping-off was also lessened in most cases by a dilution of 4:100, although neither this nor 5:100 was always so effective as acetic acid, and different samples of this pyroligneous acid were not all equally effective. Effects of these treatments on several species are here summarized.

Pyroligneous Acid Undistilled	Species Not Injured	Species Sometimes Injured
5:100	Sweet pea Petunia Mignonette Nicotiana Sweet Alyssum	English daisy Beet Cucumber
4:100	English daisy Marigold Ageratum Sweet William *Viola cornuta* Beet Cucumber	

In later experiments, a pyroligneous acid made from pine wood was applied to soil, without dilution, immediately before seeding. In amounts up to 125 cc., it did not injure beet, cress, and lettuce, and 125 cc. controlled damping-off very satisfactorily. There was considerable benefit also from 100 cc. per square foot when it was diluted to 1 liter and applied after seeding. Its use, both before and after seeding, deserves to be investigated further.

Formic Acid

According to Rideal and Rideal (76), formic acid has a higher antiseptic power than acetic acid, and Uppal (90) found it more toxic to *Phytophthora colocasiae* Rac. than acetic acid.

As used in these experiments, 7 cc. of 90 percent formic acid, diluted to 250 cc. and worked into the soil immediately before seeding, controlled damping-off very well. This effect plus the better germination, as compared with checks, resulted in marked improvements in the final stands:

	Increase in Final Stand Percent
Canterbury bells	100
Beet	442
Cress	377

Thus applied, there was no injury to *Anchusa azurea*, Canterbury bells, *Cheiranthus Allionii*, Galega, beet, and cress.

This quantity and as little as 4 cc. if applied to soil *after* seeding, was injurious to these species and to Felicia, Calendula, Linanthus, and celery. It is, however, a real fungicide, harmless enough to plants if applied to soil before seeding and its use in this way merits further investigation. It must, of course, be handled with care, because of the danger of injury to the skin.

Acetaldehyde

Acetaldehyde is known to have fungicidal properties, and Tomkins and Trout (87) found that it lessened the severity of a Penicillium rot of citrus. As used here, it was less effective against damping-off caused by Pythium and Rhizoctonia, than is formaldehyde; although dilutions of 1:30 to 1:50, applied at the rate of 2 quarts per square foot, resulted in considerable improvement in germination, especially of sweet pea.

It was also less toxic to plants than is formaldehyde, a dilution of 1:30 being harmless to pasque flower, Canterbury bells, sweet pea, Drummond's phlox and cucumber, seeds of which were sown 9 days after soil treatment. Growth of sweet pea in soil inoculated with Rhizoctonia was improved almost 100 percent by a dilution of 1:40 and its use, at least with sweet pea, is deserving of further investigation. On the whole, however, and as compared with formaldehyde, it seemed to lack toxicity to both plants and fungi.

Acetone

Acetone was found by Tomkins (86) to inhibit the growth of some fungi in the way that formaldehyde does; but, like acetaldehyde, it was less effective than formaldehyde in controlling damping-off in experiments conducted here. This was true of a dilution of 1:20 (2 quarts), and it is unlikely that heavier applications could be used safely—immediately before seeding, anyway—for even this application, 3 days before seeding, was slightly toxic to some species.

Ethyl Alcohol

Ethyl alcohol (vapor) is known (86) to retard the growth of fungi, and Roberts and Dunegan (78) found that it entirely prevented the growth of a Sclerotinia.

As used by Christoff (18), a dilution of 1:50 (about 1 quart per square foot) injured the germination of seeds of *Pinus sylvestris* L., but that may have been because he applied it to the soil after seeding rather than before.

Species vary in their tolerance of this as of other chemicals, and sweet pea was uninjured by applications which were toxic to beet and cucumber. Sweet pea was also the species most benefited by alcohol applied to the soil some days before seeding, while the growth of Arabis was not affected. Although damping-off was not altogether satisfactorily controlled by ethyl alcohol, its severity was lessened by 40 to 60 cc. of 95 percent alcohol, applied to soil 8 days before seeding, and the results, especially with sweet pea, were of sufficient interest to warrant its further consideration as a soil fungicide.

Salicylic Acid

This acid and acetic acid were found by Bitting (11) to be more actively fungicidal than are some other acids, and Dunn (32) concluded from his work that salicylic acid may be even more toxic, at least to a species of Sclerotinia, than is acetic acid. Further evidence is to be had from the results of Hermann and Neiger (47) and of Janke and Beran (53), who found that very low concentrations of salicylic acid are toxic to *Tilletia tritici* (Bjerk.) Wint. and to Trichothecium respectively. Little if any practical use seems to have been made of it as a soil disinfectant, however; although, as a crystalline powder, it has the advantage of being readily applied to soil without the necessity of first preparing either a solution or a dust.

Post-emergence damping-off, in soils heavily inoculated with Pythium and Rhizoctonia, was not usually well controlled by less than 6 gm., with better although not always complete control by 8 or 10 gm.; but germination and final stands were usually much improved by 4 to 10 gm. This fact, in the case of several species, is brought out in Table 9.

TABLE 9.—EFFECT OF SALICYLIC ACID ON FINAL STANDS

Salicylic Acid Gm. per Square Foot	Relative Number of Plants which Lived				
	Columbine	Ten-weeks Stock	Beet	Cress	Cucumber
Check	100	100	100	100	100
4	—	110	223	344	—
5	—	185	—	560	272
6	456	185	263	582	287
8	461	200	242	1280	—
10	—	209	—	1283	—

Soil pH values, 2 weeks after seeding, showed no effect from 8 gm. or less—a point to be considered in connection with effects on growth; and it may be noted further that Dunn was inclined to attribute the toxicity of salicylic acid more to the undissociated molecule than to the H-ion.

As applied to soil, immediately before seeding, salicylic acid, up to 10 gm. did not injure the germination of seeds of any species used. Its effects on their growth were as follows:

Salicylic Acid amount	Growth Injured	Growth Not Affected
10 grams	Phlox	Ten-weeks stock
8 grams	Aubrietia Sweet pea Cress	Phlox Beet Cucumber
6 grams		Aubrietia Sweet pea Cress Columbine Rocket
4 grams	*Laburnum alpinum* Foxglove	Arbor-vitae *Rhododendron carolinianum* *R. catawbiense* *R. molle* *R. Schlippenbachii*

These results, while not complete and consistent enough to warrant definite recommendations, were sufficiently encouraging to suggest the value of further experimentation with salicylic acid as a soil fungicide, at least with such species of plants as are relatively tolerant of it.

Tannic Acid

Tannic acid, as used, gave no evidence of being fungicidal, but the growth of foxglove was much improved by 3 to 6 gm. per square foot, even 19 weeks after seeding. Growth of columbine was also improved, although less than was foxglove. These treatments had no effect, however, upon the growth of *Rhododendron carolinianum*, *R. catawbiense*, *R. Schlippenbachii*, rocket and sweet pea.

Tannic acid apparently affected these soils physically, improving tilth and making them looser and less sticky, with this effect first noticeable immediately after treatment. This may be related to the response of foxglove, a species which grows well in loose-textured soils, rich in leafmold.

There is an occasional statement in horticultural literature, for example that by Durand (33), to the effect that the acidity of a moderately acid soil may be increased by tannic acid; but it did not appear in this work that such effect as tannic acid may have on plants has much if any relation to soil reaction. When it was applied to soil which had an initial pH value of 6.2, amounts up to 12 gm. did not have any effect on pH value 9 weeks after soil treatment; and 20 gm., as far as it affected soil reaction at all, made soil a little less rather than more acid 3 weeks after soil treatment. According to Laurie and Chadwick (57), earlier investigators have secured similar results, 500 pounds of tannic acid per acre having little or no effect on soil reaction.

Ammonium Hydroxide

As applied to soil by Johnson (54), ammonia did not control damping-off, and Hartley (43) concluded that its effect is too fleeting to protect conifer seedlings.

Ammonium hydroxide, if applied to soil heavily, is, however, an effective soil fungicide and it has been used successfully by Neal, Wester and Gunn (68) to

protect cotton against root rot and by Davey and Leach (26, 58) to reduce the extent of infection of sugar beets by Sclerotium. It does not necessarily follow that it would be useful against damping-off, for Neal and Gilbert (67) state that a 4 percent solution should be applied to soil at least six months before planting, and that is certainly too long to wait if only damping-off is being combated.

Ammonium hydroxide (sp. gr. 0.9, a minimum of 27 percent NH_3) diluted with water in the proportions of 1:30 to 1:80 was applied to soil (2 quarts per square foot) 8 to 15 days before seeding. Results with beet and cucumber, means for five experiments with each species, are recorded in Table 10.

TABLE 10.—EFFECT OF AMMONIUM HYDROXIDE ON DAMPING-OFF, FINAL STANDS, AND GROWTH OF SEEDLINGS

Ammonium Hydroxide Dilution	Percentages which damped-off		Relative numbers of plants which lived		Green weights per plant as relative numbers	
	Beet	Cucumber	Beet	Cucumber	Beet	Cucumber
Check	42	41	100	100	100	100
1:80	43	—	216	—	—	—
1:70	39	38	217	150	98	—
1:60	19	31	283	153	120	100
1:50	15	9	249	178	107	129
1:40	5	17	277	196	63	119
1:30	3	0	325	329	40	78

There was practically no damping-off of these or other species with a dilution of 1:30; very little with 1:40; more, although usually not much more, with 1:50; too much, although less than in the check, with 1:60; and no control with lesser concentrations. For the prevention of damping-off caused by species of Pythium and Rhizoctonia, both of which were isolated from damped-off plants, it was necessary to use dilutions of 1:40 to 1:50, which means not less than 9 gm. NH_3 per square foot.

The following treatments, by preventing pre-emergence damping-off, also improved germination unless, because of too great a concentration, there was chemical injury to some species.

Dilution of ammonium hydroxide	Time of application	Germination Improved	Germination Injured
1:40	8 days before seeding	Foxglove Canterbury bells Beet	Sweet pea
1:50 and 1:60	10 or 12 days before seeding	Foxglove Canterbury bells Mignonette Salpiglossis Lupine *Alyssum saxatile*	

Two or three times as many beet and cucumber germinated and lived (see Table 10) with dilutions of 1:50 to 1:30 as in the check.

Growth of all species was injured by a dilution of 1:30 applied to soil 10 to 15 days before seeding, and a dilution of 1:40 was a little injurious to growth of *Alyssum saxatile*, sweet alyssum, sweet pea, and beet, but not to Scabiosa. A dilution of 1:50 was usually harmless to these species and to *Cheiranthus Allionii*; and this and lesser concentrations, often too weak to prevent damping-off, improved the growth (as compared with checks) of Salpiglossis, lupine, Canterbury bells, and cucumber.

Ammonia, as a soil fungicide for the control of damping-off, should have more attention, since it is not only definitely fungicidal but also readily available and, of course, a source of nitrogen. The results may not be quite the same in all soils, however, for Davey and Leach (26) concluded that the fungicidal effect of ammonia is influenced by soil reaction. Dilutions more concentrated than 1:50 will probably be injurious to many species if applied less than 10 days before seeding, but this dilution or 1:60 may well be tried. Weaker solutions may, of course, be used nearer to the time of seeding, but that they will protect against damping-off has yet to be proved.

Ammonium Thiocyanate

Organic thiocyanates are known to be highly toxic to fungi (99), and Andes (7) concluded that ammonium thiocyanate may be used for the disinfection of soil. It is, however, so toxic to plants as to be a good weedicide (44), and Andes found it necessary to wait six weeks before tobacco seeds could be sown safely in soil treated with a 3.0 percent solution (2 quarts per square foot).

The writer used much lighter applications. Two and 3 gm. seemed to have some fertilizer value and greatly improved the growth of sweet alyssum, seeds of which were sown 16 days after soil treatment, but damping-off was not prevented by 7 gm. This amount, or even 5 gm., applied to soil 20 days before seeding, was injurious to Salpiglossis, Petunia, Canterbury bells, foxglove, and heliotrope.

Ammonium thiocyanate may, therefore, be said to remain toxic to plants too long to be a good soil fungicide, since the need is for treatments which may be used at the time of seeding or not long before.

Calcium Cyanamide

Calcium cyanamide, a nitrogenous fertilizer which is known (62, 92, 65, 12) to have some effect as a soil fungicide, was used in several experiments, the results of which are summarized in Table 11. Applications of 6 to 18 gm. were well mixed with soil, naturally infested with Pythium, 10 to 14 days before seeding. Damping-off was not well controlled by 8 gm. or less, but there was good control by 10 or 12 gm. or more.

The exact quantities necessary may, on the basis of the work of Walker and Larson (92) with cabbage club root, possibly be different in different soils; and Boning (12) found that applications too light to prevent all infection by Pythium at least delayed primary infection.

Table 11.—Effect of Calcium Cyanamide on Damping-off and on Final Stands

Calcium Cyanamide Grams per Square Foot	Beet Exp. 1	Beet Exp. 2	Beet Exp. 3	Cucumber Exp. 1	Cucumber Exp. 2	Cucumber Exp. 3	Calendula	Sweet Pea
Percentages Which Damped-off								
0	50	10	21	25	10	26	15	32
6	51	—	—	22	—	—	4	0
8	5	1	6	25	10	25	3	0
10	0	0	—	0	5	—	2	0
12	5	0	5	0	0	0	0	0
14	0	0	0	0	0	0	0	0
16	3	0	0	0	0	0	1	0
18	2	—	—	0	—	—	0	0
Relative Number of Plants Which Lived								
0	100	100	100		100	100	100	100
6	200	—	—		—	—	131	227
8	429	126	436		154	322	144	253
10	424	136	—		215	—	123	293
12	485	138	291		142	823	133	346
14	480	120	259		138	800	133	313
16	393	125	264		154	725	141	260
18	521	—	—		—	—	110	249

Germination of seeds was affected by soil treatments, as follows:

Germination Injured

Calcium cyanamide Grams	Time between treatment and seeding	Species
15	11 days	Salpiglossis
		Mignonette
14	14 days	Scabiosa
		Alyssum argenteum
16	16 days	*Oenothera fruticosa*

Germination Improved

Calcium cyanamide Grams	Time between treatment and seeding	Species
8–10	2 weeks	Calendula
		Sweet alyssum
		Sweet pea
		Beet
		Cucumber
12	2 weeks	Scabiosa
10	2 weeks	*Alyssum argenteum*
6–12	11 days	Foxglove
		Salpiglossis
		Canterbury bells
		Mignonette

Calcium cyanamide was injurious to growth of all of the preceding species, also to *Anchusa myosotidiflora*, when 15 gm. were applied to soil 10 to 14 days before seeding. So applied, 10 gm. were not harmful, except to Calendula; and 12 gm. did not injure Anchusa, *Alyssum argenteum*, sweet pea and cucumber. Six to 10 gm. improved the growth of Anchusa, Alyssum and Scabiosa and might have so affected other species had final readings been taken later, when seedlings were older.

If the necessary delay between soil treatment and seeding is not considered too serious an objection, more use might well be made of calcium cyanamide as a preventive of damping-off. It is not to be recommended, however, in the case of Ericaceous plants or others which prefer an acid soil, for it is known (65) to increase the pH value of soil, 100 pounds of calcium cyanamide having a lime value equal to about 70 pounds of hydrated lime; and in a soil used by the writer an initial pH value of 6.4 was raised to 6.7 by 14 gm. per square foot.

One ounce for 2 to 4 square feet of soil is about 14 to 7 gm. per square foot, and these are the amounts which may be used experimentally, with different species, in different soils and at different lengths of time before seeding. For increased safety, as a consequence of its more rapid decomposition (23), calcium cyanamide should be thoroughly mixed with the soil. The soil should be moist; and the poorer and more sandy it is, the longer should be the interval, according to McCool (65), between soil treatment and seeding.

The time interval necessary between soil treatment and seeding—during which the nitrogen of the cyanamide is changing into the urea and the ammonia forms—will also depend on the species of plant and, unless experience has shown that it may be shorter, should probably be about 2 weeks in the case of the quantities necessary to control damping-off.

Table 12.—Effect of Calcium Hypochlorite on Growth of Seedlings

Calcium Hypochlorite Gm. per Square Foot	Days before Seeding	Species Injured	Species Not Injured
28	21	China aster Physostegia Heliotrope Foxglove	Ten-weeks stock
20	14	China aster Physostegia Heliotrope	Ten-weeks stock
14	7	Physostegia Heliotrope	Ten-weeks stock China aster
12	15	Foxglove Sweet pea Regal lily Snapdragon *Anchusa azurea*	
4	13	*Centaurea macrocephala* Beet Cucumber	Nasturtium Sweet alyssum

Calcium Hypochlorite

Calcium hypochlorite, chlorinated lime, or bleaching powder, often called chloride of lime, has fungicidal properties (14, 91). That used by the writer contained 26 to 30 percent available chlorine and was applied, dry, to soil some days or weeks before seeding.

Germination was not injured so much as was growth and in some cases was even improved by the treatments named in Table 12. The severity of damping-off was in some cases lessened also, but this disease was not consistently prevented and there was too much chemical injury (see Table 12) to most species of plants the seeds of which were sown 1 to 3 weeks after soil treatment.

Gratz (39) made the similar observation that enough of this chemical to kill plants (cabbage) was not enough to prevent their infection by Rhizoctonia, and a heavy application used by Small (81) did not protect tomato seedlings against this fungus.

This is not a chemical which, in effective amounts, may be used safely with most species immediately before seeding, and the time interval between soil treatment and seeding with safety is not likely to be short. It is, of course, less injurious to some species than to others, and the one least injured in these experiments (see Table 12) was ten-weeks stock. According to Loew (59), the length of time which is necessary between soil treatment with calcium hypochlorite and seeding, may be affected by the character of the soil, with the interval shorter in soils rich in humus and low in clay. He used about 19 gm. per square foot without injury to cabbage and beet, but these were not planted until 2 months after soil treatment—a delay which many growers would consider as undesirable as the risk of damping-off without any treatment.

Other Calcium Salts

As was discussed earlier, it does not appear that damping-off is ordinarily controllable by the use of calcium in the form of lime. Albrecht and Jenny (4) observed less damping-off of soybean, however, when they used calcium acetate and calcium chloride and they concluded that calcium concentration is more important than H-ion concentration in affecting damping-off. They made no observations as to infecting fungi, and their seedlings often damped-off in spite of sterilization of soil and seeds by other means. It is, therefore, at least possible that fungi may not have been the cause at all, for plant ailments of very different origin may be much alike in symptoms.

The calcium salts here named were applied by the writer to soil inoculated with Pythium and this fungus was isolated from seedlings which damped-off. The disease was not controlled by calcium chloride in amounts sufficient to injure Ageratum, Myosotis, and mignonette. Calcium acetate was less injurious, but heavy applications, up to 30 gm., did not control damping-off.

Calcium sulfate, gypsum, even 50 gm. per square foot, also failed to control damping-off, although 20 to 35 gm. did improve the growth of seedlings of sweet pea, but not of lavender and Delphinium. It is occasionally recommended in horticultural literature for the control of root rots of pea, and the growth of legumes in some soils has, according to Cubbon (24), been benefited by it; but the results in this work were not such as to warrant its recommendation as a soil fungicide.

Riviere and Pichard (77) concluded that calcium sulfite has a temporarily antiseptic action in soil. Apparently it is not very pronounced, however, for 10 to 25 gm., used in these experiments, did not control damping-off satisfactorily.

Potassium Permanganate

This is sometimes applied to soil by British horticulturists (83, 22) with the object of controlling damping-off. It is occasionally mentioned in the American literature, also; and there are statements, usually without supporting evidence, to the effect that potassium permanganate is a soil disinfectant. Thus Connors (21) believed that its fungicidal value is known; Hunn (49) asserted that it sterilizes a rooting medium (for cuttings); and Wiggin (98) was of the opinion that plant propagators can check damping-off with it.

Such really experimental evidence as was found in the literature points in the other direction and leads to the belief that potassium permanganate is not a reliable soil disinfectant. According to McCallan and Wilcoxon (64), solutions were not toxic to spores of Botrytis and Sclerotinia which were suspended in them; and White (96) found it ineffective in preventing infection of cuttings by Pythium. Concentrations of solutions and rates of application are variously expressed, but, when translated to number of grams per square foot of soil, 3.5 gm. potassium permanganate did not satisfactorily protect cuttings of geranium against Pythium (Gill, 37); Brien and Chamberlain (13) were unable to protect tomatoes against Pythium by 13 gm.; 20 gm. had no apparent sterilizing action on soil in Buddin's experiments (16), and failed to protect tomatoes against Rhizoctonia in the work of Small (81).

As used by the writer, potassium permanganate up to 50 gm. per square foot never controlled damping-off caused by Pythium and Rhizoctonia. It is unlikely that heavier applications could be used, for growth of most species was injured by 50 gm., while the germination of China aster was injured by 40 gm. and that of sweet pea by 30 gm.

There was, however, improved growth of Aubrietia, hollyhock, beet, and cucumber with 15 and 20 gm.; and it should be noted in this connection that Webster and Robertson (94) observed marked growth response of various plants to potassium permanganate. They concluded, from work with a species of Opuntia, that the good effect of the permanganate on growth is not wholly, or is something more than, manurial.

Potassium permanganate, in these experiments, made a slightly acid soil less acid. Chadwick (17) concluded that the effect of this salt on the reaction of a medium is not the same for all media, and his results, like those of the writer, make it appear that the statement by Hunn (49) that potassium permanganate acidifies a rooting medium is not always correct.

On the basis of these results, potassium permanganate cannot be recommended for the protection of seedlings against damping-off. This is not to say that it is always useless in the propagation of plants vegetatively, for there is then more involved than the mere prevention of damping-off and there is evidence in the literature that potassium permanganate sometimes improves the rooting of cuttings. Curtis (25) found that to be the case when it was applied to cuttings of woody plants. Carnation cuttings rooted better when Connors (21) watered the rooting medium with a solution of potassium permanganate, about 3.5 gm. of the salt per square foot; and in the experiments of Chadwick a solution of about 1 pound in 15 gallons, 2 quarts per square foot, improved the rooting of cuttings of most species of woody plants used by him. It does not follow that potassium permanganate is a soil fungicide, and the explanation of Curtis seems adequate. He noted that cultures containing the permanganate were not sterile and suggested that its beneficial effect on rooting may be due to its increasing the respiratory activity of the cutting by hastening oxidation. This view seems to be

strengthened by the results of Zimmerman (103), who found that oxidizing agents such as potassium permanganate improve the rooting of cuttings, but that aeration alone may be even more effective.

Charcoal

Charcoal is mentioned at this point, for it too is occasionally recommended, as by Macself (61), for a soil treatment to check the spread of damping-off, although there seems to be little or no experimental evidence on which to base such a recommendation. Chupp (19) observed that there was almost no damping-off in a steamed soil with which a grower had mixed powdered charcoal, but the steaming alone could, of course, account for that, and Chupp did not assert otherwise.

Powdered wood charcoal 1 to 4 ounces per square foot, worked into soil before seeding, did not control damping-off or improve germination. Powdered charcoal is sometimes used, as Taylor (84) says, with rooting media for cuttings; but when the writer so used it, up to 3 ounces per square foot, there was no significant effect on the rooting of cuttings (taken July 1) of *Enkianthus subsessilis*, *Lonicera syringantha*, *Rhododendron arbutifolium* and Persian yellow rose.

Charcoal is said (2) to lessen the danger of injury to plants by a too acid soil; but if so, it is not by changing soil reaction, for, in these experiments, 4 ounces or less did not affect pH values of soil 54 days after soil treatment.

Charcoal 1 to 4 ounces did not affect growth of seedlings of Aubrietia, heliotrope or sweet pea, but did significantly improve the growth of nasturtium. This improvement was first evident 2 or 3 weeks after germination and continued for 5 to 10 weeks or as long as the plants were under observation, with most benefit from applications of 2 to 4 ounces.

Aluminum Sulfate

Several investigators (97, 56, 52) have successfully used aluminum sulfate for the protection of conifers against damping-off. Not much use has been made of it with other species, although Weindling and Fawcett (95) found that 30 gm., raked into soil before seeding, protected citrus seedlings against Rhizoctonia.

Aluminum sulfate, in solution, was applied to soil before seeding. Damping-off caused by Pythium and Rhizoctonia, more often by the latter, was not affected by 10 or 15 gm., was less severe with 20 or 25 gm., but was never eliminated by less than 30 gm. The exact quantities necessary would probably not be the same in all soils, for Jackson (52) found that an application which lessened the severity of damping-off of conifers at pH 3.5 was not as effective at pH 6.5. By preventing some pre-emergence damping-off, 25 to 30 gm. improved the germination of Calendula, China aster, several species of Dianthus (see Table 13), foxglove, sweet pea, and Nicotiana.

There was no injury to germination of any species by 28 gm., nor to Calendula, China aster, and Nicotiana by 35 gm., while seeds of all species of Dianthus used germinated without injury by 44 gm.

Soil pH values were lowered, in 8 weeks, from an initial value of pH 6.5 to pH 6.0 by 20 gm. and to pH 5.7 by 25 gm. These effects might, of course, be different in different soils.

There was more injury to growth than to germination. Results are recorded in Table 13. Seedlings of beet, a species which McLean and Gilbert (66) found very subject to injury by aluminum, and China aster were injured by 20 gm.,

and Petunia, Nicotiana and *Primula polyantha* were not much less sensitive. It is not likely that aluminum sulfate can be used safely for the protection of such species. Calendula and sweet pea were less injured, and most tolerant of all were the species of Dianthus, for they were not injured by 44 gm. and their early growth was, in fact, improved by 20 gm.

TABLE 13.—EFFECT OF ALUMINUM SULFATE ON GROWTH OF DIFFERENT SPECIES

Species	Not injured by	Injured by
	Gm.	*Gm.*
Calendula	30	35
China aster	15	20
Dianthus sps.*	44	—
Foxglove	20	28
Laburnum	—	25
Lupine	20	30
Nicotiana	20	25
Petunia	15	25
Primula polyantha	20	25
Snapdragon	28	35
Sweet pea	30	40
Beet	15	20
Cucumber	20	30

*All the species of Dianthus which are named in the appendix.

Copper and Copper Salts

The copper salts here mentioned were very thoroughly mixed with soil which had been inoculated with Pythium, for, as was shown by Hunt and his co-workers (50), their penetration in and through soil is poor. No use was made of Rhizoctonia, against which several investigators (70, 85, 79, 38, 97, 89) have found copper salts rather ineffective. Especial attention was paid to their effects on germination and on growth of seedlings, for the literature suggests that copper in soil-fungicidal quantities may be far from safe to some species.

Metallic Copper Powder[1]

This metallic copper, manufactured electrolytically in crystalline form, gave some degree of control of damping-off when not less than 10 gm. was applied to soil before seeding; but the growth of several species (mignonette, foxglove, sweet alyssum, *Viola cornuta*, snapdragon, heliotrope, *Pentstemon ovatus*, China aster, sweet pea, and Calendula) was injured by it.

Cuprous Cyanide

There was little or no damping-off with 2 gm. cuprous cyanide; but no salt of copper used was any more toxic to plants, especially to Ageratum, Petunia, Salpiglossis, beet, and cucumber, and 2 gm. injured germination of beet and cucumber more than did 3.5 gm. copper carbonate. Hollyhock was the only species satisfactorily protected by cuprous cyanide without some chemical injury.

[1]Copper powder, "B" metal from United States Metals Refining Company.

Copper Sulfocarbolate

Copper sulfocarbolate, up to 4.5 gm., gave less satisfactory control of damping-off than did some other copper salts; and 4.5 gm., although not at all injurious to hollyhock, was injurious to ten-weeks stock, Petunia, Myosotis, Ageratum, Salpiglossis, sweet pea, beet, and cucumber.

Copper Aceto-arsenite

Copper aceto-arsenite (Paris green) 0.5 gm. did not control damping-off, but there was little of the disease with 1.0 gm., less with 1.5 or 2 gm., and usually none with 2.5 gm. or more. Applications of more than 1.5 gm. were unsafe, however, for they injured the germination of seeds of all species used except hollyhock. Harmful effects on growth were even more evident, as little as 0.5 gm. injuring pyrethrum and Myosotis, while 1.0 gm. was toxic also to seedlings of sweet pea, Salpiglossis, Ageratum, marigold, Leiophyllum, Laburnum, and arbor-vitae. Hollyhock was the species most tolerant of this as of the other copper salts, being uninjured by 2.0 gm., and it was the only species protected against damping-off by copper aceto-arsenite without some chemical injury.

Copper Carbonate

According to Newhall and his associates (70), copper carbonate may be applied to soil at the rate of 1 pound to 100 square feet, which is about 4.5 gm. per square foot; but, as used by other investigators (71, 6), 4.0 gm. injured tobacco, and in the work of the writer, more than 4.0 gm. injured the germination of all species except hollyhock. Even lighter applications interfered with growth, cucumber being injured by 2.0 gm., Delphinium by 3.0 gm., and Ageratum, Petunia, and Salpiglossis by 3.5 gm.

Of the species used, only hollyhock and possibly beet showed sufficient lack of chemical injury to suggest that copper carbonate in effective quantities may be used safely with them, for less than 4.0 gm. did not satisfactorily control damping-off. Hollyhock was the species most tolerant of this as of other copper salts, and although injured by 6.0 gm., it was not at all affected by 5.0 gm. or less.

Copper Sulfate

Copper sulfate 3 to 4 gm. usually lessened the severity of damping-off, but the disease was not often wholly controlled by less than 4.5 gm. Germination was also improved by 3 to 5 gm. and with this as with other copper salts, there was usually less chemical injury to germination than to growth.

Copper Sulfate Grams	Growth Injured	Copper Sulfate Grams	Growth Injured
1.5	Canterbury bells	3	Snapdragon Mignonette Ageratum Salpiglossis
2	*Anemone coronaria* *Viola cornuta*		
2.5	Calendula China aster	3.5	Sweet pea Cucumber Beet

Hollyhock, growth of which was uninjured by 4.5 gm., was the only species with which copper sulfate, in quantities really effective against damping off, was used without too much chemical injury.

Copper-lime Dust

An English recommendation which is mentioned by Newhall and his associates (70) calls for about 22 gm. (per square foot) of a 10-90 copper-lime dust. This is equal, on basis of copper content, to about 11 gm. of a 20-80 dust, which was used in these experiments. Such an application did not prove heavy enough, for less than 20 gm. of the 20-80 dust did not give satisfactory control of damping-off. Control was usually good with 25 and 30 gm., not so good with 20 gm.

Applications up to 30 gm. did not interfere with the germination of seeds of *Anemone coronaria*, Delphinium, Salpiglossis, hollyhock, mignonette, and *Lilium tenuifolium* and, by the prevention of some pre-emergence damping-off, often improved it. Statice and sweet pea, however, were injured by 20 gm., beet and cucumber by 25 gm., and hollyhock and mignonette were the only species not injured by 30 gm.

When effects on both damping-off and growth of seedlings are considered, copper-lime dust gave as good results as did any copper fungicide. Its use, in quantities really effective against damping-off, would, however, have to be limited to those species of plants which are least susceptible to chemical injury by it. It makes soil less acid, and an application of 25 gm. to soil with an initial pH value of 6.5 resulted in a pH value of 6.8 eight weeks later. For this reason, copper-lime dust would not be indicated for use with species known to prefer a more acid soil.

With copper-lime dust as with the copper salts above mentioned, the greater tolerance of hollyhock was evident. It is of interest in this connection that Eriksson (34) reported no injury to hollyhock growing in soil which he watered with a 0.3 percent solution of copper sulfate, for, if such watering was long continued, there must have been a considerable accumulation of copper in the soil about the roots of the plants. Cotton, another member of the Malvaceae, may be tolerant of copper also, for in the work of Fikry (35), cotton plants were not injured by a heavy application of copper sulfate to the soil in which they grew.

Copper Oxalate

Copper salts, in spite of the limitations above mentioned, may sometimes be useful in protecting against Pythium the seeds and seedlings of such species as germinate so slowly that a volatile chemical would be gone from the soil long before protection was most needed. Copper oxalate, 6 gm., was applied to soil immediately before sowing seeds of the umbrella pine. They germinated 3 months later. Damping-off was well controlled, without chemical injury, and the stand was increased nearly nine-fold compared with the checks, while there was little if any benefit from acetic acid. Quick (74) has used copper oxalate similarly and successfully as a soil fungicide for the protection of seeds of *Ribes roezlii* Reg. during their stratification.

Mercuric Chloride

Mercury salts are apparently more effective against Rhizoctonia in the soil than are copper salts; but mercury salts may be just as injurious to plants, and it is important to know the quantities which may be expected to be effective against fungi and at the same time safe to use.

In the experiments of Jackson (51), China asters were protected against Fusarium wilt by "soaking" the soil with a 0.1 percent solution and there was no chemical injury. One quart of such solution contains about 0.95 gm. of the salt

and that is the quantity which, in the work of Beach (8), protected lettuce against Sclerotinia although plants were injured chemically. A dilution of 1:1600 had some effect in protecting violets against Rhizoctonia (72), and as little as 0.12 gm. (per square foot) was effective, in the experiments of Wiant (97), in protecting conifers against Rhizoctonia. Stands of tomato were injured by 0.44 gm., not by 0.22 gm., as used by Thomas (85); and as light an application as 10 to 15 pounds per acre (about 0.10 to 0.15 gm. per square foot) was observed by Macleod and Howatt (60) to be associated with reduced yields of potatoes.

The writer applied mercuric chloride, 1 or 2 quarts of the solution per square foot, to soils which had been inoculated or were naturally infested with both Pythium and Rhizoctonia. There was sometimes some damping-off with 0.95 gm., equal to 2 quarts of a 1:1000 solution, or 1 quart of a 1:2000 solution per square foot. There was little or no damping-off with applications heavier than 1.0 gm. per square foot, but such applications were very harmful to germination or growth of some of the species named in Table 14, although a number of species, notably Salpiglossis, Petunia, lupine, sweet pea, and English daisy, finally outgrew most of the earlier chemical injury.

TABLE 14.—EFFECT OF MERCURIC CHLORIDE ON GERMINATION AND GROWTH

Species	Germination		Growth	
	Not injured by	Injured by	Not injured by	Injured by
	Gm.	*Gm.*	*Gm.*	*Gm.*
Arabis	—	1.5	—	1.5
Canterbury bells	—	1.0	—	1.0
Dianthus chinensis and *D. plumarius*	2.5	—	1.5	2.0
English daisy	3.0	—	1.0	1.5
Foxglove	—	1.5	—	1.5
Heliotrope	—	1.5	—	1.5
Lupine	2.5*	—	1.75	2.2
Pansy	1.5	2.0	—	1.0
Petunia	1.7*	2.5	1.5	2.5
Salpiglossis	2.0*	—	2.2	2.7
Sweet pea	2.5*	3.0	2.0	2.2
Rhododendron molle and *R. yedoense* var. *poukhanense*	—	1.5	—	—
Beet	2.5	3.0	—	2.0
Cucumber	1.7	2.0	—	1.5

*Germination improved.

The species least injured as regards growth and most benefited as regards germination were Salpiglossis, Petunia, lupine, and sweet pea, and with these the use of mercuric chloride as a soil fungicide appears to deserve further investigation.

Zinc Sulfate

As a supplement to seed treatment with red copper oxide, which does not wholly prevent post-germination damping-off, Horsfall (48) successfully used zinc oxide 0.5 to 1.0 ounce per square foot, applying it to the surface of the soil after seeding. He did not find zinc sulfate safe although germination of tomato was in some cases improved and damping-off was at least partly controlled by 10 gm.

The sulfate is, of course, much more soluble and might, in the absence of seed treatment, be expected to give more protection than the oxide. Zinc sulfate was accordingly used in these experiments with the thought that it may be less harmful to some species than to tomato and useful at least with them. It was always applied to soil before seeding and in solution.

Post-emergence damping-off, caused principally by Pythium, partly by Rhizoctonia, was not completely controlled by less than 16 gm., but there was usually some control of pre-emergence damping-off, with germination improved accordingly, by 12 gm. or more. Zinc sulfate, however, in quantities effective against damping-off, interfered somewhat with the growth of most species used, as shown by the following tabulation.

Zinc Sulfate	Growth Injured	Growth Not injured
10 gm.	Heliotrope	
	Physostegia	
	Ten-weeks stock	
	China aster	
	English daisy	
12 gm.	Foxglove	Pansy
	Beet	Sweet pea
	Cucumber	*Iberis sempervirens*
		Oenothera missouriensis
		Sweet William
14 gm.		Sweet William
		Sweet pea

Sweet William and sweet pea were the only species which were at all satisfactorily protected against damping-off by zinc sulfate without some chemical injury.

Sulfuric Acid

Sulfuric acid is known to have some value as a soil disinfectant and it has been used by other investigators (43, 88, 42) for the control of damping-off of conifers. Recommended rates of application per square foot vary considerably, from about 3 to about 14 gm., diluted with water and applied to soil at the time of seeding. Even these quantities have been found to be unsafe in some soils and with some species, and as little as 5.1 gm. was observed by Toumey and Li (88) to retard the growth of seedlings of white pine, spruce, and hemlock. Not much use seems to have been made of it with herbaceous plants.

The writer diluted sulfuric acid (95 percent, sp. gr. 1.84) so as to give the desired number of grams of this acid per square foot when 2 quarts of the solution were applied. Seeds were sown within 24 hours after soil treatment. Soils used had initial pH values of 6.4 to 6.6. Soil pH values, 8 weeks after treatment in a

typical instance were: check, 6.4; 6 gm., 6.2; 9 gm., 5.7; 12 gm., 5.5; and 16 gm., 5.0.

The severity of damping-off, most of it caused by Pythium, some by Rhizoctonia, was lessened by 9 gm., but infection was not satisfactorily controlled by less than 12 or, more often, 15 gm.

These and even smaller quantities were injurious to most species. Growth of beet and cucumber was retarded by 6 gm., that of English daisy by 9 gm. Twelve grams interfered with the germination of Delphinium, Salpiglossis, *Viola cornuta*, and Canterbury bells, but not of Dianthus, the genus least injured by this acid. Growth of *Dianthus barbatus*, *D. latifolius*, *D. plumarius* and *D. alpinus* was a little injured at first by 14 gm., but most or all of this injury was later outgrown.

Sulfuric acid 10 gm. improved germination of seeds of *Rhododendron calendulaceum*, *R. carolinianum*, *R. catawbiense* and *R. Schlippenbachii* in a sandy, peaty soil (initial pH value 5.8), without injury to growth. The use of sulfuric acid, in this way, with ericaceous plants, is now being investigated further

Of the other plants used, only the species of Dianthus were sufficiently tolerant of sulfuric acid to suggest that it may possibly be used with them.

Sulfur

As is well known, the addition of sulfur to soil may, by increasing soil acidity, have an inhibiting effect on certain soil fungi. There is no reason to suppose that damping-off would be controlled in this way, however; for, as has already been noted, the disease may be severe even in an acid soil, and Buddin (16) concluded from his work that sulfur does not sterilize soil. Townsend (89), too, found sulfur ineffective in protecting (lettuce) plants against a disease caused by Rhizoctonia. It is nevertheless occasionally mentioned in horticultural literature as a soil treatment for the prevention of damping-off and some experimental use was accordingly made of it.

Flowers of sulfur, up to 20 gm. per square foot or more than 1900 pounds per acre, was well mixed with soil immediately before seeding. Soil pH values, 5 weeks later, were lowered from 6.3 to 5.8 by 8 gm. and to 5.0 by 20 gm., but damping-off, caused by Pythium, was no less severe with 6 to 20 gm. than it was in untreated soil.

Six grams (or more) of sulfur interfered with the growth of beet and cucumber seedlings, but foxglove was uninjured by 8 gm., and sweet pea, for the first ten weeks, by 10 gm.

SUMMARY

Damping-off is not altogether controllable in practice by regulating and adjusting the environment (soil temperature, moisture, and reaction), for conditions preferred by the fungi are too nearly the same as those preferred by the plants. For example, the watering of small seeds from below is advisable for other reasons, but damping-off is not always prevented by it.

In washed sand or in sand-sphagnum or in sand-peat moss, there was very little damping-off as compared with that in soil. However, growth of all species was poorer in sand, even with nutrient, than in soil and usually better in sand-sphagnum or in sand-peat moss (with nutrient) than in sand.

To lessen the cost of using soil which has been purchased already sterilized, it was sometimes diluted with washed sand. Growth of seedlings was satisfactory and there was no increase in damping-off.

Increase in knowledge of better methods of using old soil disinfectants and other chemicals, possible new soil disinfectants which may have more nearly ideal qualities, makes it evident that a soil treatment which is good for some species of plants may be not so good or even injurious to others. Thus charcoal, although not a fungicide, improved the growth of nasturtium; and calcium sulfate had a similar effect on sweet pea, but on sweet pea alone.

Damping-off was not controlled by calcium sulfate, acetate, or chloride or by materially raising soil pH values with hydrated lime.

The most common evidence of stimulation of growth of plants observed following the use of soil fungicides, occurred when Rhizoctonia, in untreated soil, so interfered with growth that plants in treated soil, and therefore free from the fungus, grew better. Exceptions are chemicals which contain nutrients as do calcium cyanamide and ammonium hydroxide.

Damping-off was well controlled by calcium cyanamide and more use might well be made of it when the necessary delay between soil treatment and seeding is not considered too objectionable. This is true also of ammonium hydroxide which prevented damping-off and was, as used, harmless to most species. Ammonium acetate was less effective.

Ammonium thiocyanate in the soil also remained toxic to plants for too long a time to be a good soil disinfectant, for there is more need of such as can be used at or about the time of seeding.

The time interval between soil treatment and seeding depends partly on the species of plant involved; and formic acid, formaldehyde, acetic acid (and vinegar) were, in general, less injurious to seeds which germinate slowly than to those which germinate rapidly.

Formic acid controlled damping-off and is not ordinarily harmful if worked into the soil before seeding.

Another promising material was salicylic acid. Final stands of seedlings were often much improved by it and it has the advantage of being readily applied to soil without the necessity of first preparing either a solution or a dust.

Tannic acid gave no evidence of being fungicidal, but growth of foxglove was benefited and it apparently improved the soil physically.

There were indications that less of a fungicide, for example formaldehyde, is necessary if not too much water is applied with it. Less than one-fifth as much formaldehyde as was formerly used controlled damping-off when the quantity of water used with it was also much reduced.

Damping-off was controlled by acetic acid dusts and they were not injurious to most species when applied to soil the day before seeding. They were, however, very toxic to softwood cuttings.

Undiluted vinegar, applied to soil immediately before seeding, controlled damping-off, usually without injury.

Quantities of acetic acid, formaldehyde, and other volatile chemicals which were safe enough if worked into the soil immediately before seeding were injurious

if applied to the surface of the soil immediately after seeding, for they are then more concentrated near the seeds.

Crucifers were more often injured by acetic acid and by formaldehyde than were most of the other plants used.

Too little vinegar to prevent damping-off was injurious if applied after the emergence of seedlings.

Damping-off was well controlled by pyroligneous acid (from pine wood) and this was not injurious when applied to soil immediately before seeding.

Acetaldehyde was less toxic both to plants and to fungi than was formaldehyde and, in infested soil, sweet pea grew better with it. Sweet pea, germination and growth, was apparently benefited by ethyl alcohol also.

Calcium hypochlorite is not a chemical which, in effective quantities, may be used safely with most species immediately before seeding. The interval of time between soil treatment with calcium hypochlorite and seeding with safety is not likely to be short.

Heavy applications of potassium permanganate did not control damping-off, and its occasional recommendation for this purpose is not justified.

Inorganic salts, such as those of copper, may have a use in protecting seeds and seedlings of such species as germinate so slowly that a volatile chemical would be gone from the soil long before protection is most needed. Seeds of a species which required three months to germinate were not well protected by acetic acid, but were by copper oxalate.

Copper-lime dust, with other species, gave as good results as did any copper salt, but all salts of copper were too toxic to many species of plants, with hollyhock showing the greatest tolerance.

Aluminum sulfate in quantities injurious to many other species was perfectly safe with Dianthus. Species of Dianthus and species of Rhododendron were notably tolerant of sulfuric acid also. There was no evidence that sulfur is a soil disinfectant.

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APPENDIX

Ornamental Plants Used in the Experiments

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